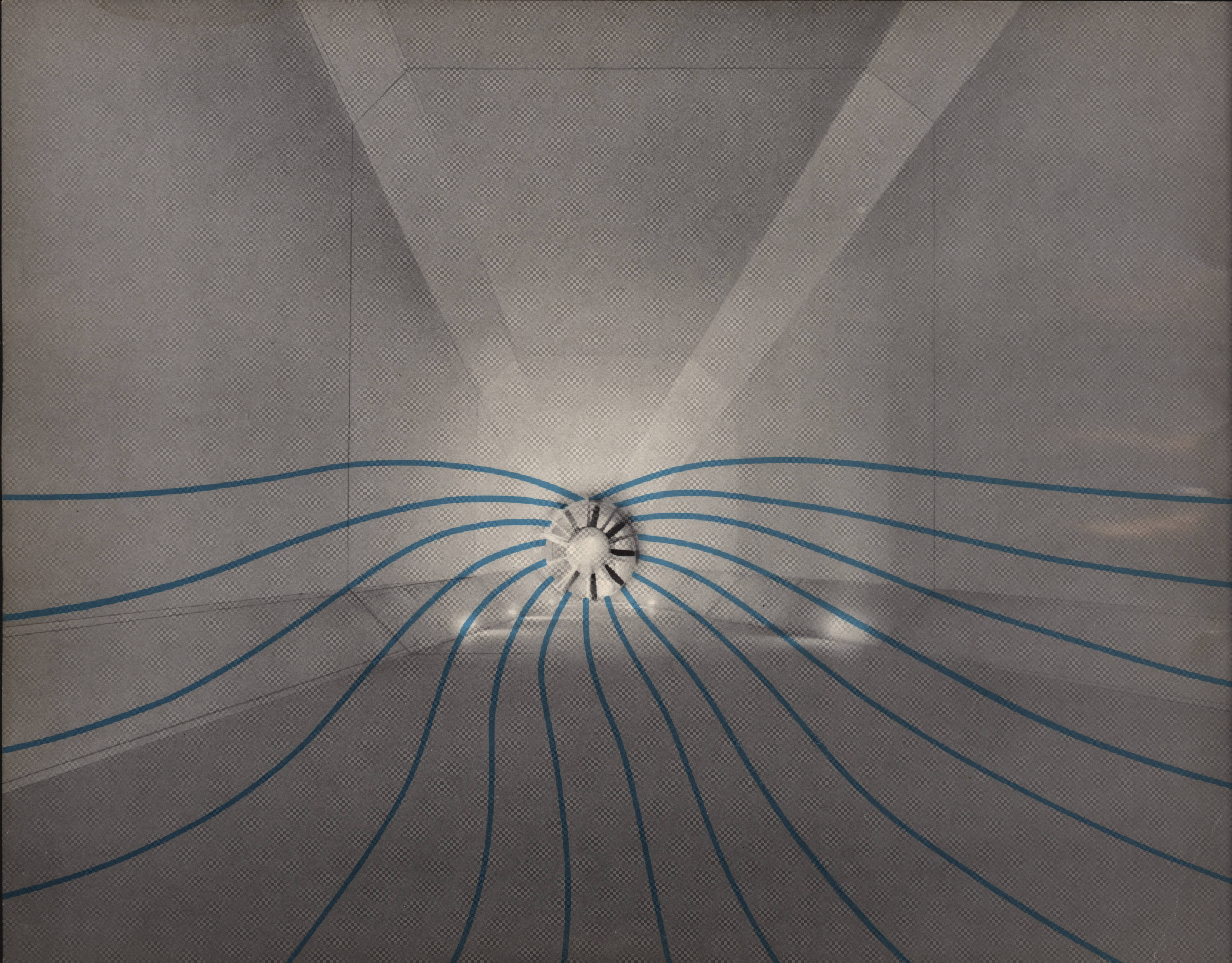
BOEING V/STOL
WIND TUNNEL

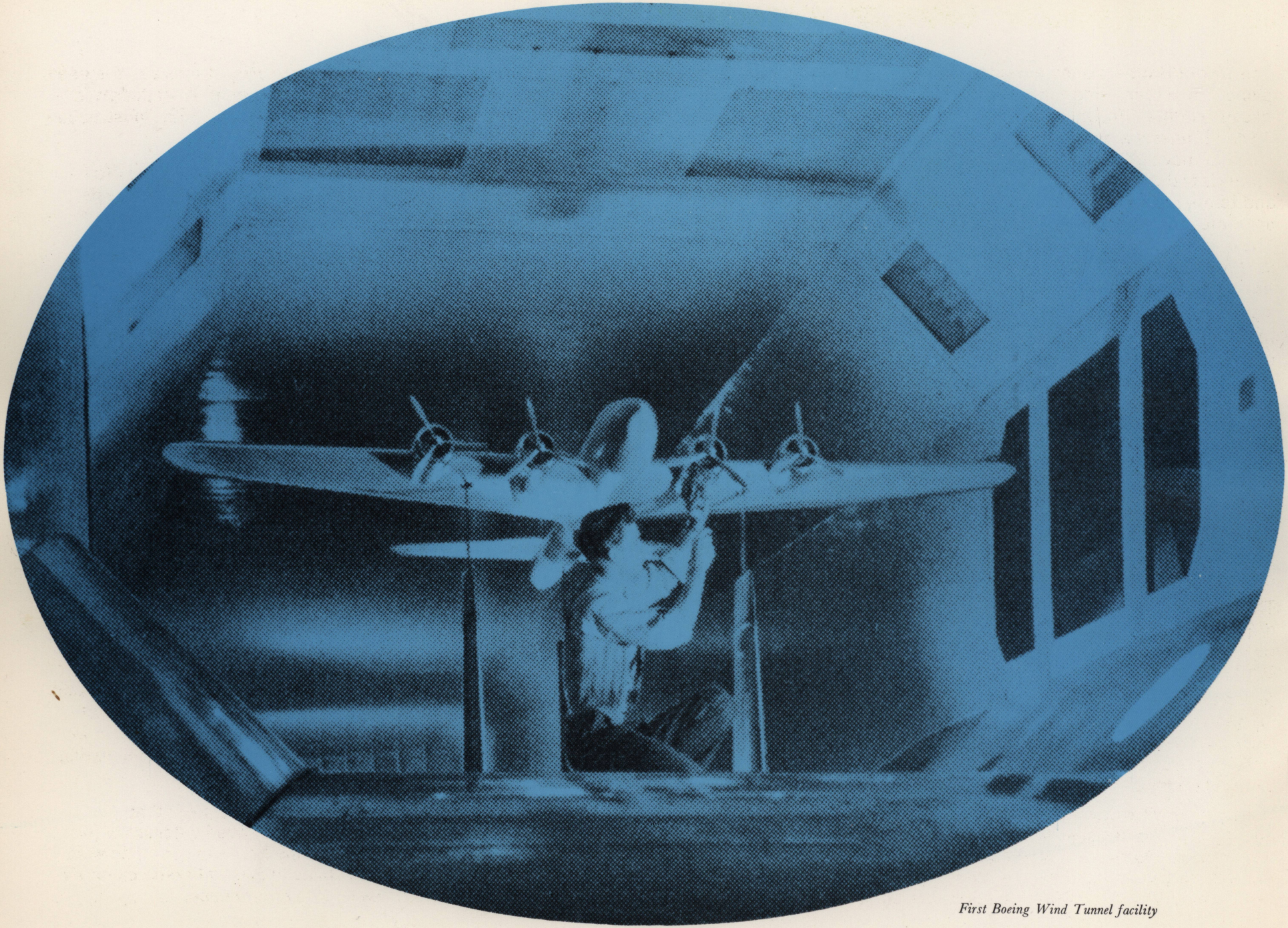


INTRODUCTION

This booklet describes the Boeing V/STOL Wind Tunnel, which is the most recent addition to the aerodynamic testing facilities of The Boeing Company. It is operated by the Vertol Division and is located at Eddystone, in suburban Philadelphia.

Although the tunnel was specifically built to support the design and development of V/STOL aircraft, it can be used for all types of low-speed wind tunnel testing. This new wind tunnel is the most advanced testing facility of its kind in the world and is unique because of its versatility. The wind tunnel complex was designed to be an autonomous test facility. Within the complex, models can be designed, manufactured, instrumented, and tested. A complete modern data system, with on-line computing capability, provides engineers with final corrected data immediately for analysis.

This facility will contribute to the development and improvement of current aircraft, such as the Sea Knight, the Chinook, the 747, and the SST, and will play a prominent role in the development of V/STOL and other future aircraft concepts.



First Boeing Wind Tunnel facility

BACKGROUND AND HISTORY OF BOEING WIND TUNNEL

The Wright Brothers used a wind tunnel before they flew their first plane. Since then, wind tunnels have become even more necessary because of the difficulty of testing new configurations in actual flight. A wind tunnel is a device for moving air past an aircraft model instead of moving the model through the air. The purpose of a wind tunnel is to derive data concerning the aerodynamic forces, pressures, and temperatures experienced by a model, so that the flight characteristics of a given configuration may be determined. The design refinements reflected in the B-52, the B-47, the 707—in fact, all modern aircraft—require wind tunnel testing during development.

Before World War II, Boeing depended upon wind tunnel facilities at universities and U. S. Government laboratories for testing programs. Boeing paid a share of the construction costs for the University of Washington wind tunnel completed in 1939, and from then until 1944, about 70 percent of the university wind tunnel testing time was used by Boeing.

Test requirements were increasing rapidly, and Boeing management realized that wind tunnel testing would be essential for all future aircraft designs. Planning for the first Boeing facility was begun in 1940. It was designed to have a speed range limit of about Mach 0.95, using some of the best features of existing tunnels. A 1/20-scale model of the tunnel was built and served to determine optimum design for each section of the full-sized tunnel.

This subsonic tunnel was completed in the spring of 1944 at a cost of $750,000. It was used in the creation of the first swept-wing jet bomber, the B-47 Stratojet, and in the design development of the B-52 Stratofortress.

As aircraft speeds increased, generation of test data from velocities in the vicinity of sound became necessary. In 1948, studies by the National Advisory Committee for Aeronautics (NACA) showed that transonic speeds could be obtained in a wind tunnel using the principles of a slotted test section or ventilated throat.

Boeing engineers studied these concepts in a model wind tunnel, and in 1950 the decision was made to redesign the subsonic tunnel for transonic operation. The modification involved major changes in the test section, fan and motors, and air exchanger, and required 18 months and $1,750,000. It was completed in April 1953.

But even before the transonic tunnel was ready to operate, the need for testing in supersonic ranges became apparent. Final design for a supersonic tunnel was begun in the summer of 1953. Construction was completed in August 1957 at a cost of $2,250,000.

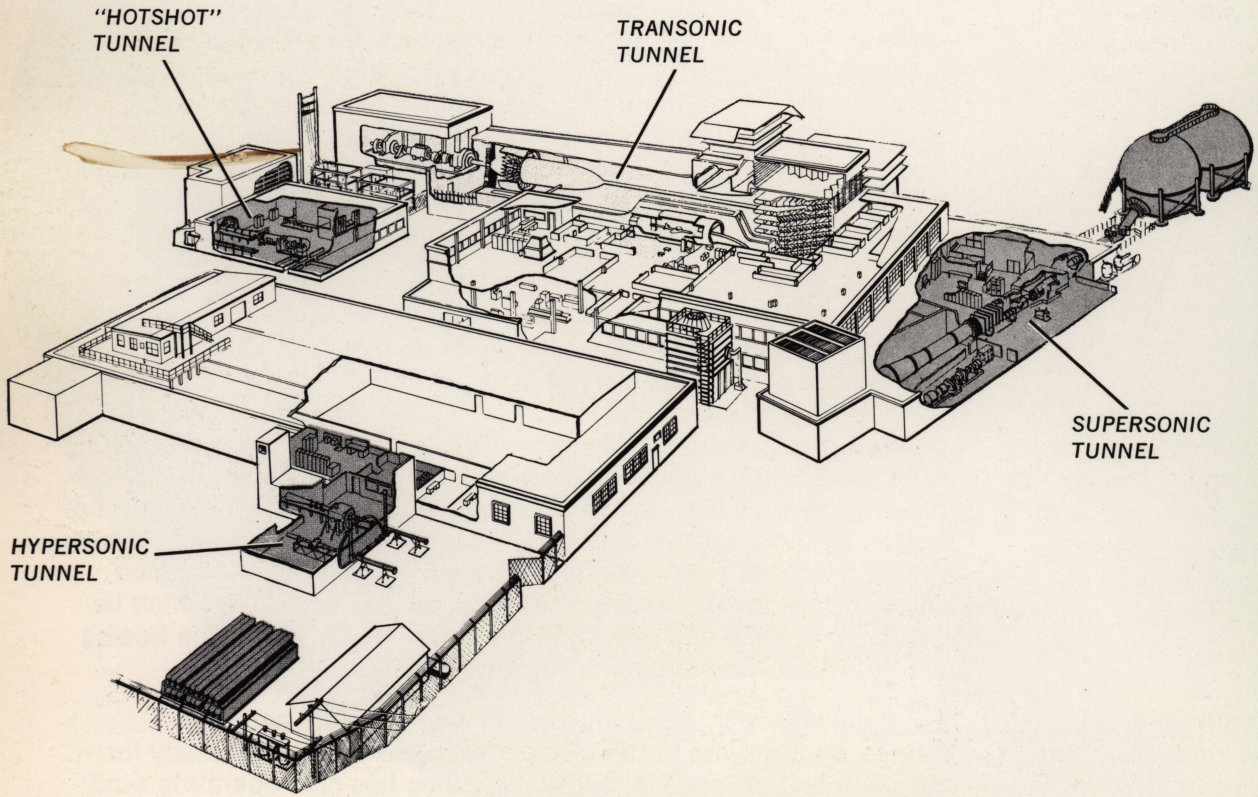
With increasing work on missiles, it was less than two years after the start of construction on the supersonic tunnel, and before its completion, that initial studies were begun for a hypersonic wind tunnel with velocities from Mach 5 to Mach 10. Construction of a pilot hypersonic tunnel was started in the late spring of 1957. By early summer, the tunnel was operating up to speeds of Mach 7.5 at temperatures of 1,000° Fahrenheit.

The drive for greater and greater speeds continued. Research into satellite and re-entry problems requires data from speeds above Mach 10. Again, hardly had the hypersonic wind tunnel been put into operation when design was begun on a hypervelocity facility. In the summer of 1960, it was ready for operation, after feasibility of its design had been proved with a scale model. This million-dollar tunnel extended the research range to more than 25 times the velocity of sound.

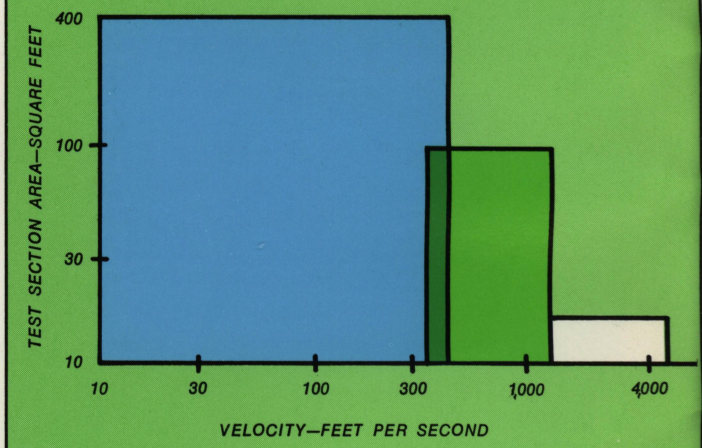
By 1964, it had become apparent that the drive for speed had left a gap in wind tunnel testing. What was needed now was a low-speed tunnel designed specifically to handle testing of V/STOL aircraft. So in that year, a program was initiated at the Vertol Division to identify the requirements for a V/STOL Wind Tunnel. Boeing engineers recognized that the corrections for wall interference for closed throat wind tunnels were approximately equal to, but opposite in sign from, those of an open throat wind tunnel. This suggested that a mixture of wall conditions, such as a slotted throat, would eliminate wall effects. An experimental program of this concept yielded the test section configuration for the Boeing V/STOL Wind Tunnel. Construction began in April 1966 and operation started in March 1968. The Boeing V/STOL Wind Tunnel cost more than $8 million.

Looking backward, it was only a little over 25 years ago that a privately owned wind tunnel was first considered a necessity for research and development. Today, Boeing has nine operating wind tunnels which, combined, provide ability to conduct research on air vehicles which operate from sea level to outer space.

BOEING WIND TUNNEL COMPLEX AT SEATTLE



CAPABILITY OF BOEING WIND TUNNELS

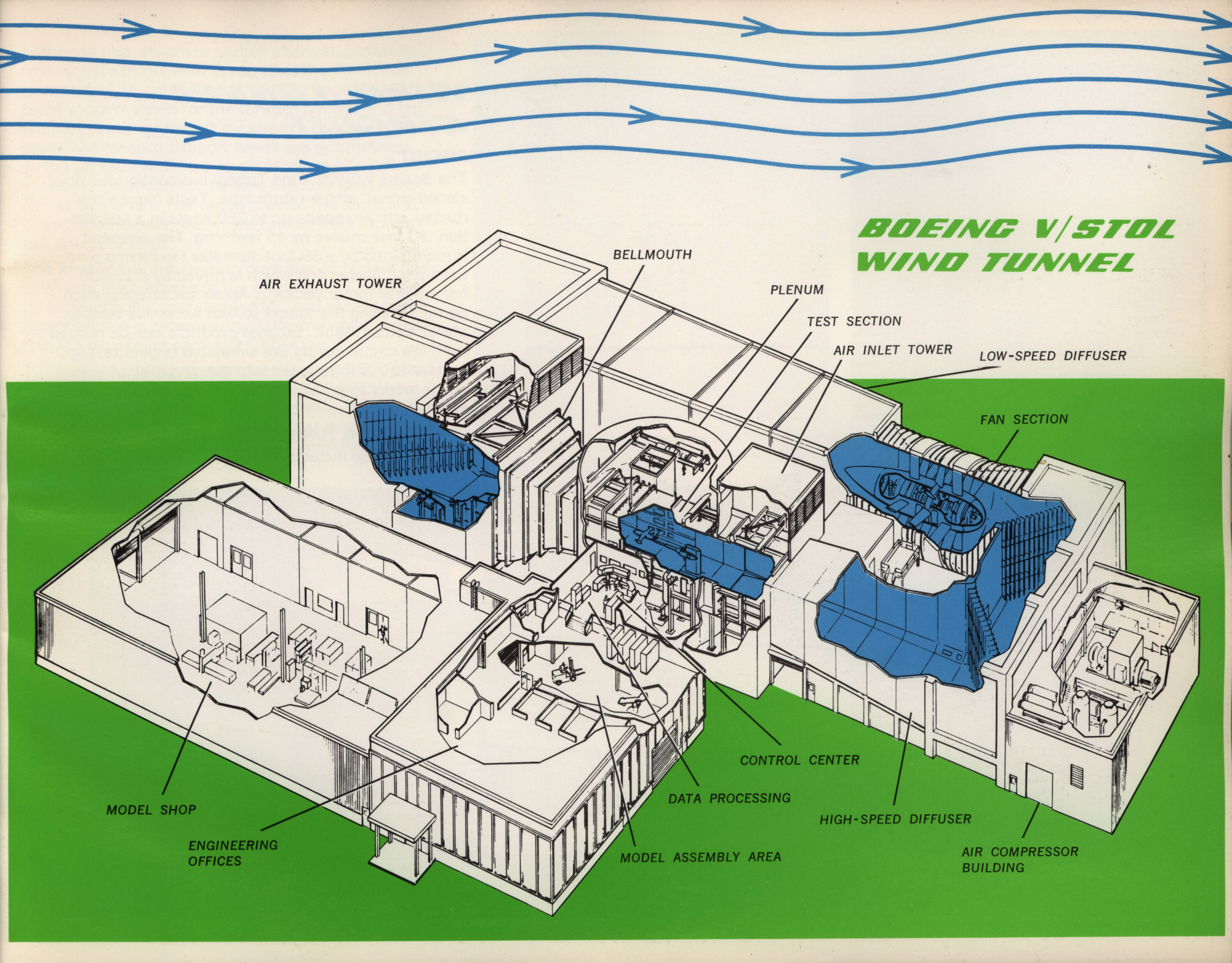


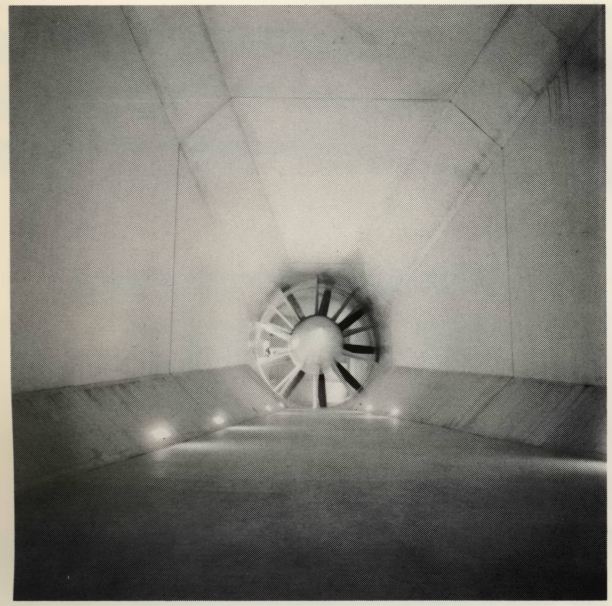
BOEING V/STOL WIND TUNNEL

BOEING TRANSONIC WIND TUNNEL

BOEING SUPERSONIC WIND TUNNEL

BOEING V/STOL WIND TUNNEL





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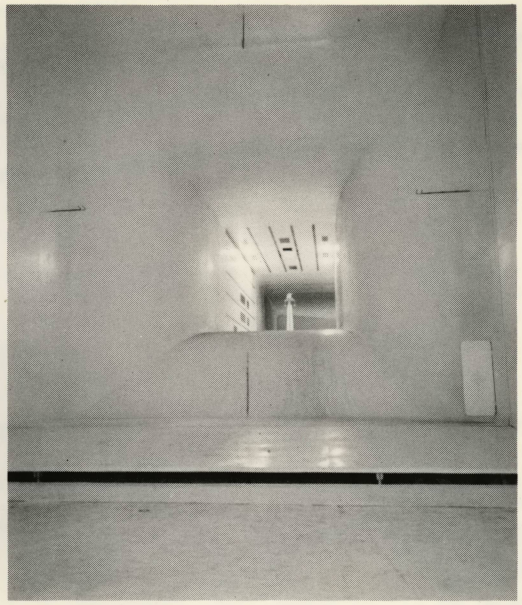
Low-speed diffuser



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This view of the Bellmouth shows three of the four air exhaust doors

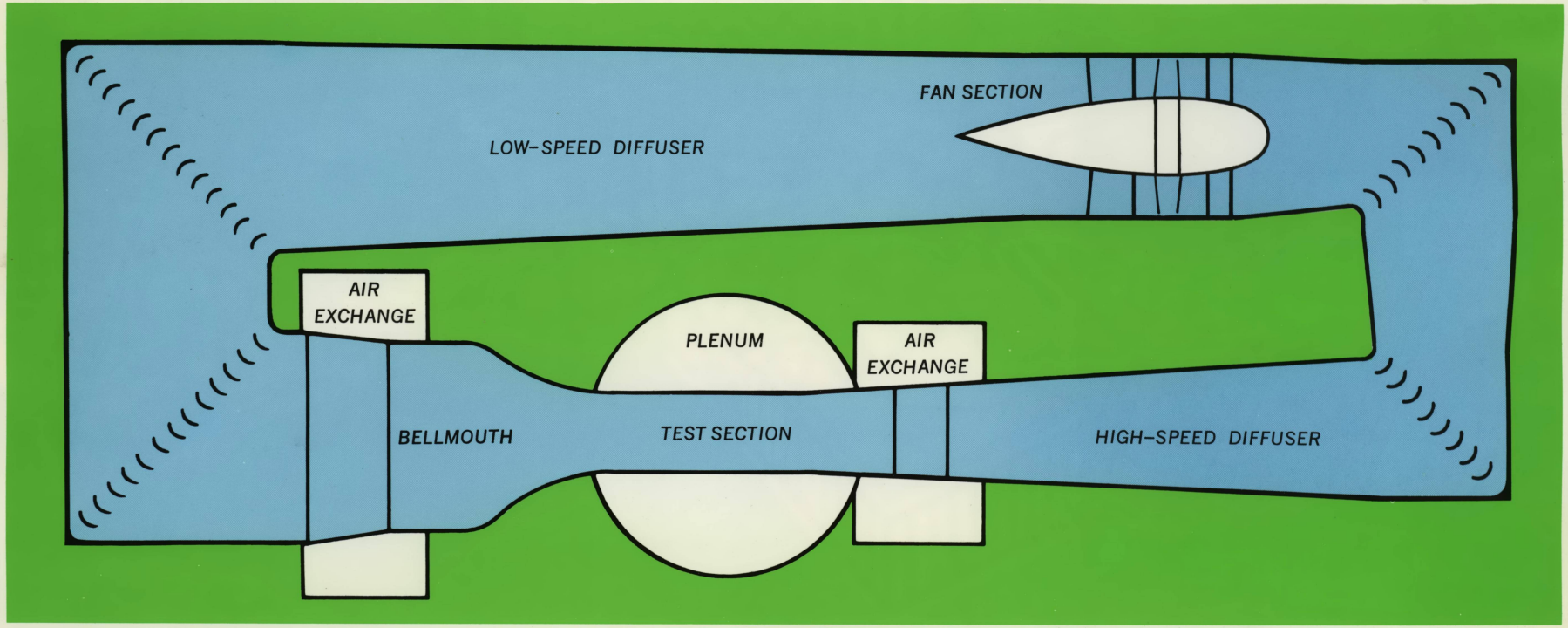
WIND TUNNEL CIRCUIT

CIRCUIT

The Boeing V/STOL Wind Tunnel is a continuous-flow, closed-circuit, single-return type. Tests can be conducted with airspeeds up to 260 knots in a test section 20 feet square by 45 feet long. The airspeed is maintained by a 39-foot-diameter fan having nine fixed-pitch blades and which is driven by a 15,000 horsepower motor package. An air exchange system permits cooling the tunnel so that excessive temperatures do not result. Exhaust products can be purged from the circuit during live simulated engine testing. Ambient air is introduced into the circuit at an air intake tower and is removed at the air exhaust tower.

FAN SECTION & TUNNEL DRIVE SYSTEM

The fan section includes the approach and exit ducting

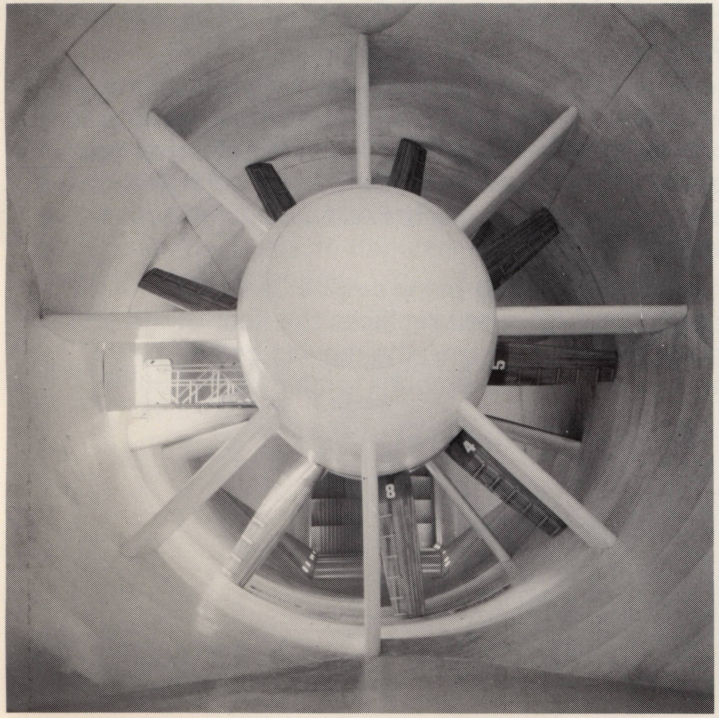


Circuit Schematic

of the fan ring. Its cross section changes gradually from square at the inlet to round at the 39-foot-diameter fan, to octagonal at the fan section exit. Eight support vanes for the forward nacelle and ten support vanes for the aft nacelle are constructed of steel. The forward support vanes are symmetrical airfoil sections with zero angle of attack. The aft vanes are positioned to remove the flow swirl introduced by the fan. The vanes provide the structural support for the nacelle, which contains the motors, fan hub, and shaft.

The nacelle has a maximum diameter of 18 feet and is 75 feet long. Access to the aft nacelle is provided by an electrically operated ladder, and access to the motor section is provided by platforms which extend into the nacelle on each side of the fan.

The tunnel fan drive system consists of a 1,500 horsepower DC motor in tandem with a 13,500 AC induction motor. The DC motor, alone, controls speeds up to 100 miles per hour. Speeds greater than 100 miles per hour are controllable by the AC motor coupled with the DC motor.



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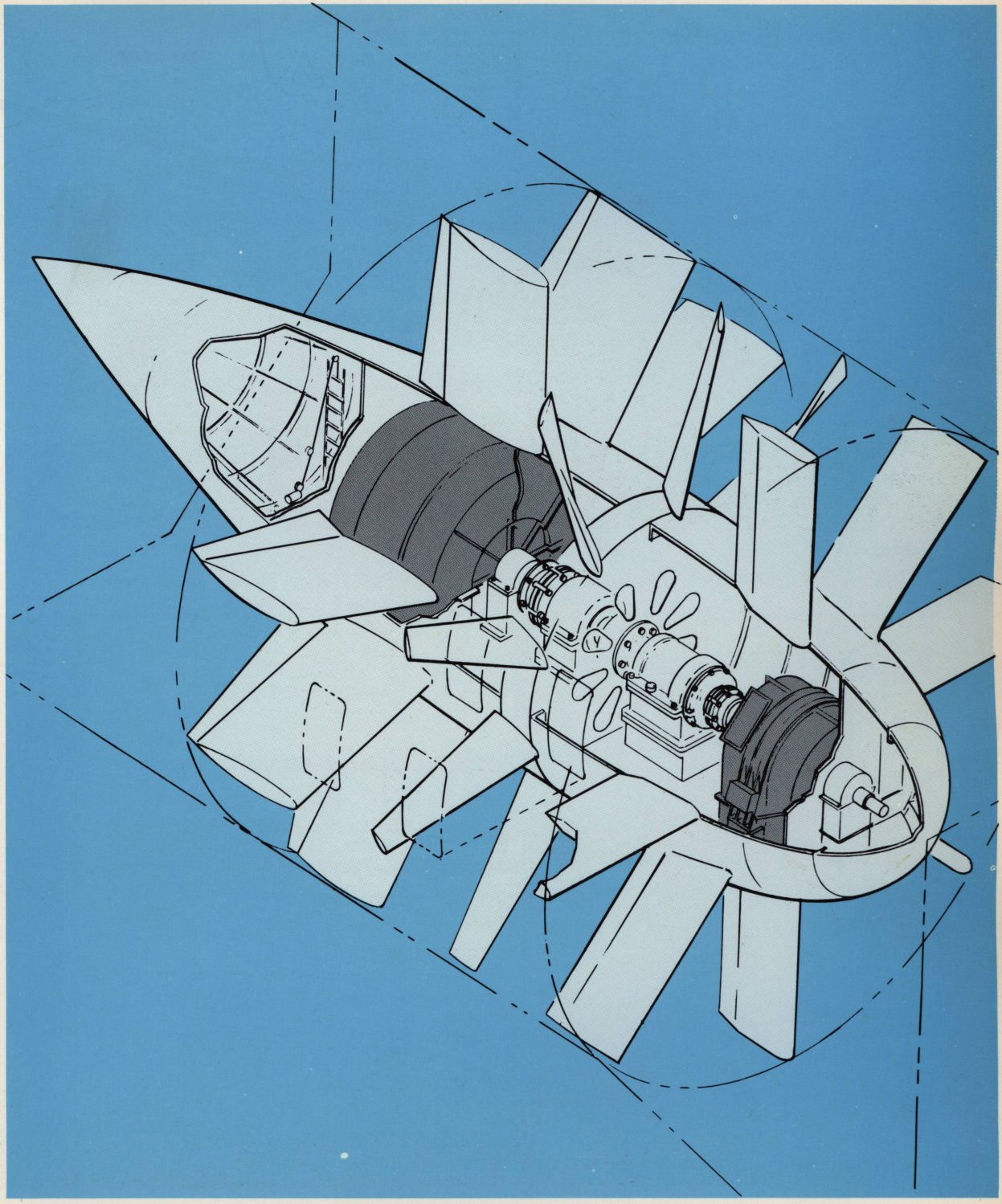
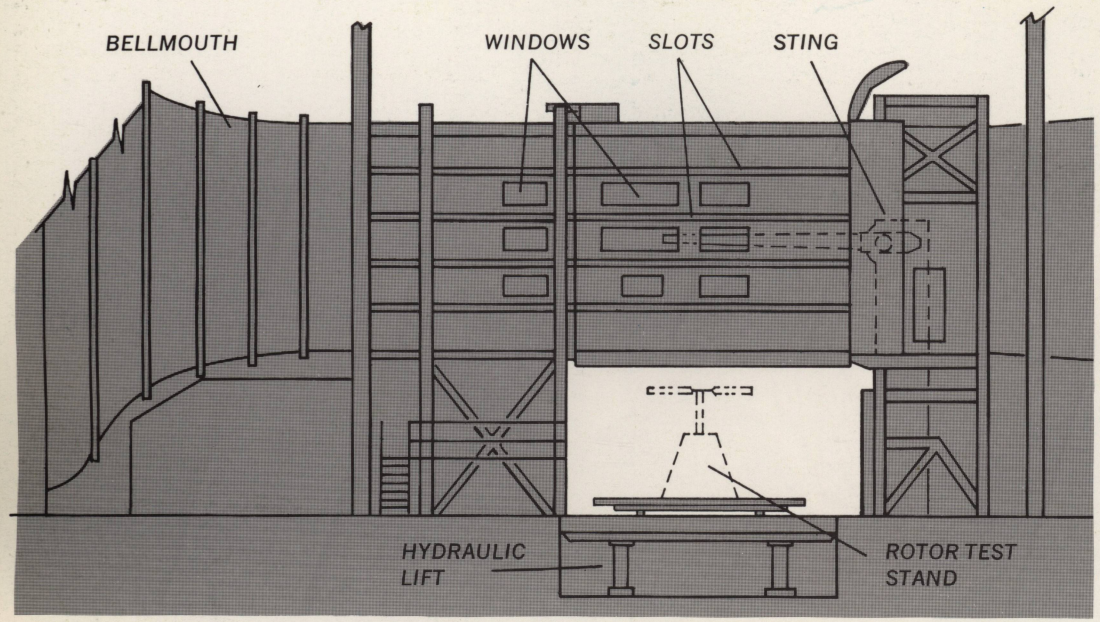
The 39-foot-diameter, 9-bladed fan system

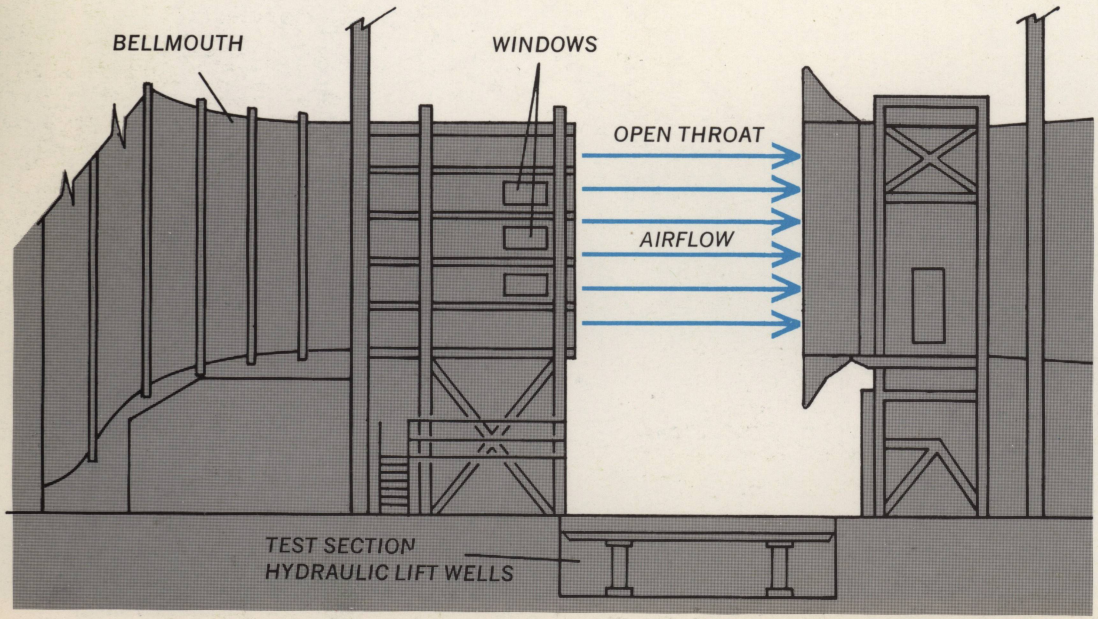


Fan section and tunnel drive system

CLOSED OR SLOTTED THROAT TEST SECTION CONFIGURATION



OPEN THROAT TEST SECTION CONFIGURATION



TEST CAPABILITY

TEST SECTION

The Test Section is 20 feet square in cross section, 45 feet long in the closed or slotted throat configuration, and 23 feet long in the open throat configuration. Three test section configurations are available in the V/STOL Wind Tunnel, namely: closed throat, open throat, and slotted throat. The walls, floor, and ceiling used for the closed throat configuration are used also for the slotted throat by simply removing covers from slots which are built in the walls. To convert to the open throat test section, the floor, ceiling, and side-walls are removed. Collectors attached to the re-entry doors are rotated into place to form a bellmouth to collect the open jet flow.

The ceiling and side-walls are moved with an overhead crane system while the floor is moved with a hydraulic lift which is installed in the floor of the plenum. The plenum is a 65-foot diameter concrete structure enclosing the test section and observation platforms.

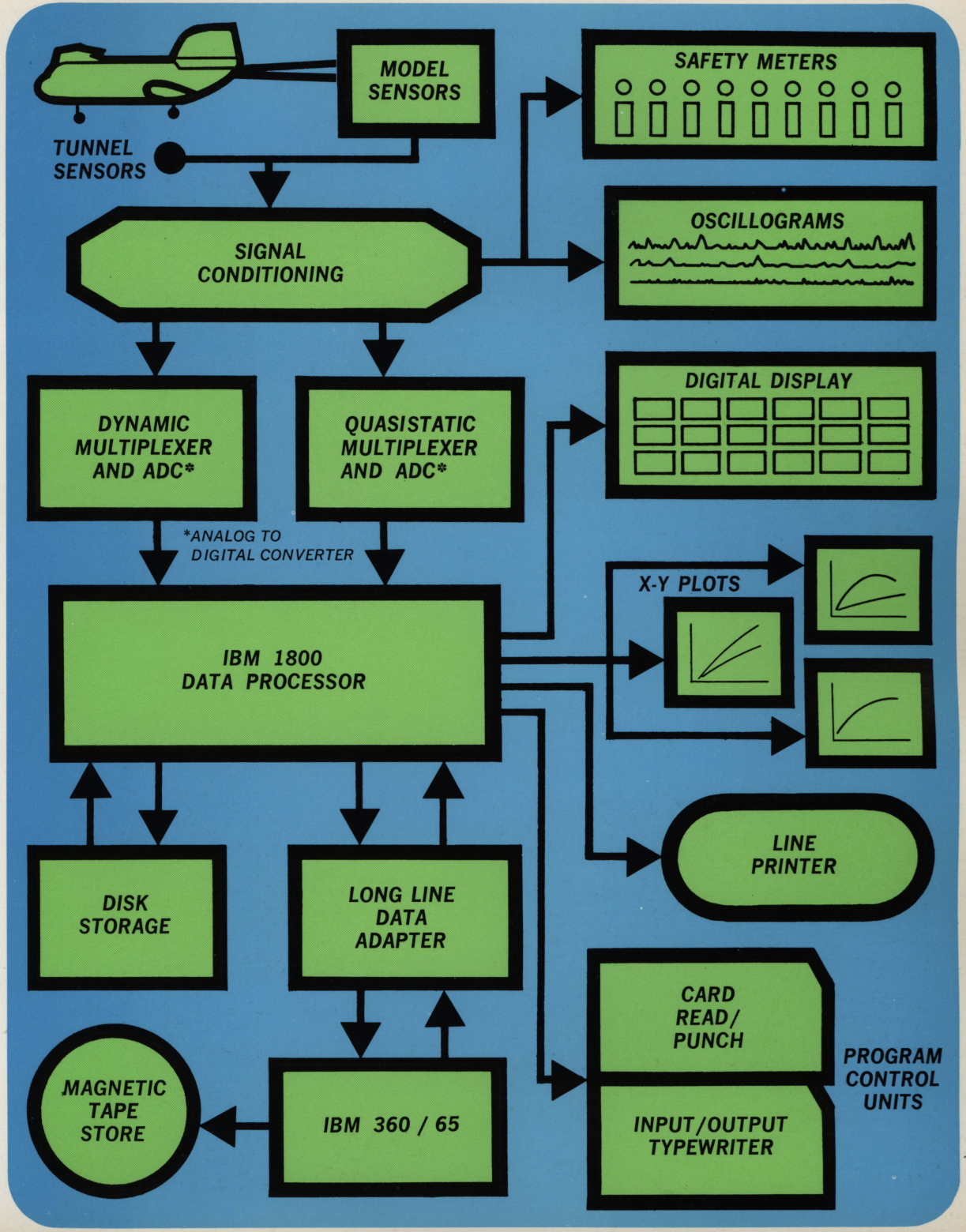
A moving belt ground plane can be used to simulate ground effect. This belt replaces the floor of the test section. When not in use, the moving belt is stored in a rack below the bellmouth section of the tunnel.

DATA SYSTEM

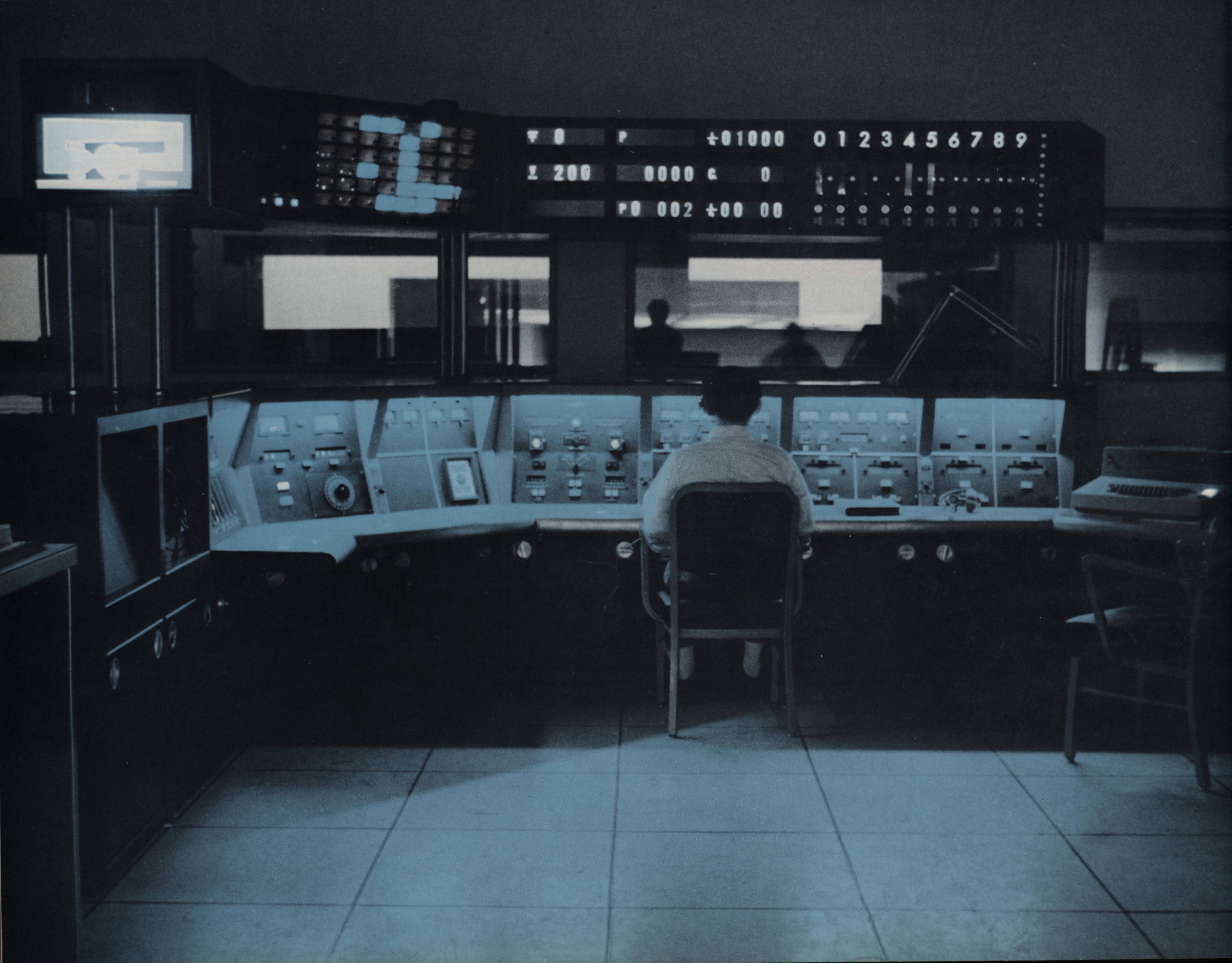
The data system will accept 120 channels of data from a model undergoing test and from the tunnel itself. These signals are routed, as illustrated in the functional block diagram, to an IBM 1800 computer for processing and outputting in final report format—X-Y plots and tabulations. The data system can support three model programs simultaneously—one in the test section, one in hover test, and one in check-out or calibration.

Test monitoring capabilities are provided by safety-of-test meters, oscillograms, and digital displays. The two signal paths shown in the functional diagram (quasistatic and dynamic data) differ only in the frequency preservation afforded. The dynamic data system has a capability of handling 62,500 samples per second. This gives the system the capability of performing dynamic data analyses in digital form. The quasistatic multiplexer has a maximum sampling rate capability of 10,000 samples per second.

The function of each component of the block diagram is outlined briefly as follows:



Data system schematic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Wind Tunnel control console

Signal Condition: Signal conditioning accepts signals from sensors, such as strain gages, resistance temperature detectors (RTD), thermocouples, and potentiometers. Individual power supply adjustment is provided, as well as zero setting and amplification, as required, to allow all signals to be adjusted for maximum sensitivity at full scale output.

Multiplex/Analog-to-Digital Conversion: In this function, each signal is sampled in a sequential pattern and is converted into a digital signal, then fed into the IBM 1800.

Data Processor: The digital signals are entered into the IBM 1800 computer and are stored on magnetic disks prior to processing. Final storage is provided on magnetic tape. Quasistatic data is processed within the 1800 computer. Dynamic data is transmitted, via a high-speed data link, to an IBM 360/65 computer in the Division's central computing facility. This more sophisticated unit performs the required analyses of the dynamic data and transmits the computed results back for output on the Wind Tunnel plotters and printers.

Data system and control console

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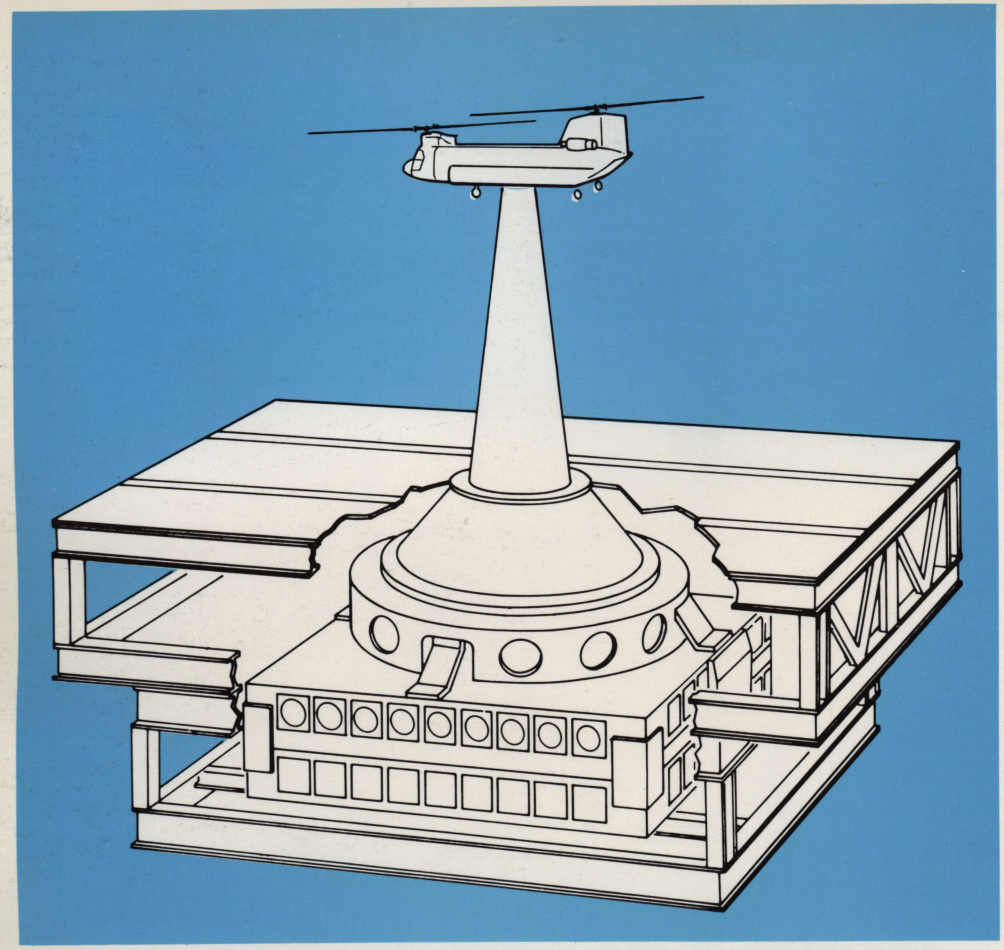
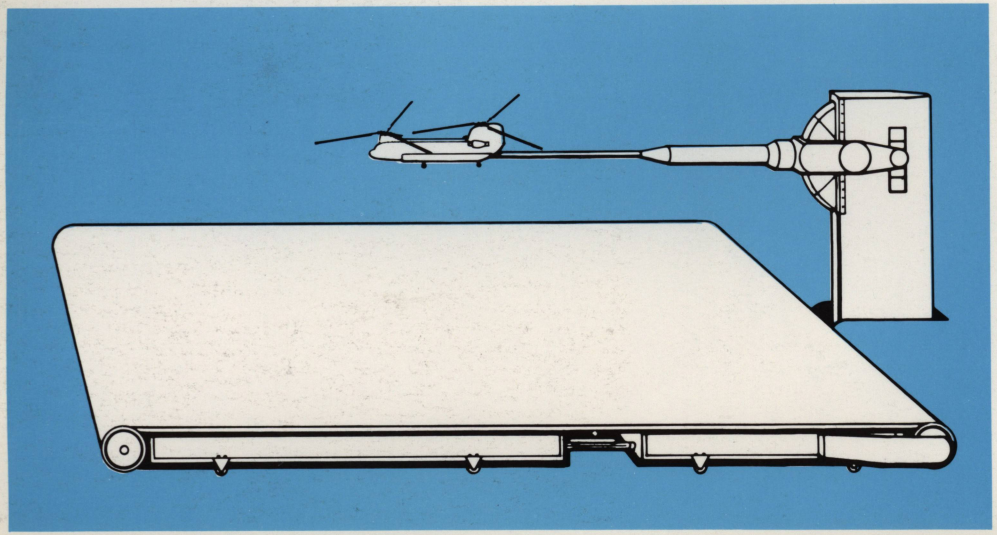


Strain gage external balance



Moving belt ground plane

TEST AUXILIARIES

BALANCE SYSTEMS

Most of the models to be tested will use internal strain gage balances. The tunnel is now equipped with several balances. Additional balances will be provided as required.

An external strain gage balance system is in process of design and fabrication. This system will permit testing of strut-mounted full models and floor-mounted half models.

MOVING BELT GROUND PLANE

The V/STOL Tunnel features a moving belt ground plane for in-ground-effect testing to 100 knots. The moving belt ground plane consists of an 18-foot-wide endless belt,stretched between rollers spaced 27 feet apart. An electrical motor drives the downstream roller through a range of speeds varying from 5 knots to a maximum of 100 knots. The speeds of the belt and airstream are displayed continuously to show the degree to which the two are matched.

AUXILIARY AIR SUPPLY

Some tests may require auxiliary air for simulation of jet exhausts, boundary layer control and/or jet-flap development. Auxiliary air for such tests is provided by a 20-pound per second, 1,000 pounds per square inch compressor system. The dew point of this air test is —80° Fahrenheit, and the total temperature is approximately 60° Fahrenheit.

The compressor system is controlled in the motor control center. The air supply to the model is regulated by means of a servo control system operated from the main control console. This system is a continuous flow supply using a total of 8,000 horsepower to drive the compressors. Filtration is provided to keep the contamination of the air below five parts per million, with the maximum particle size less than 5 microns.

THE STING

A model support system called a sting mount is provided for mounting models over the moving belt ground plane for in-ground-effect testing, or in the center of the test section for out-of-ground effect. The sting is a horizontal strut extending upstream from the re-entry section of the test section.

Vertical traverse of the sting assembly is from one foot to 16.5 feet off the floor. Angular traverse is ±20 degrees with a straight sting. With custom-designed offset stings, the angular range can be offset to cover, for instance, from −5 degrees to +35 degrees. The sting assembly has a disconnect joint 19 feet 6 inches aft of the center of the test section. The removal of the sting forward of this point allows the sting system to be lowered completely from the test section. A second disconnect joint is provided on the sting assembly 8 feet 6.5 inches aft of the center of the test section. The disconnect at this location permits the adapting of custom-designed stings as required for new models.

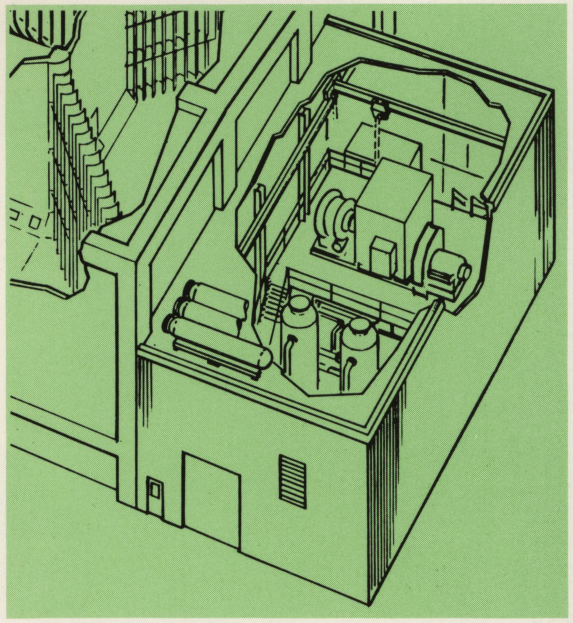
MOVABLE OBSERVATION PLATFORM

Movable observation platforms, located on each side of the test section in the plenum, provide a means for servicing the test section walls and positioning an observer at any vertical height outside the test section, so that he can view the model in test.

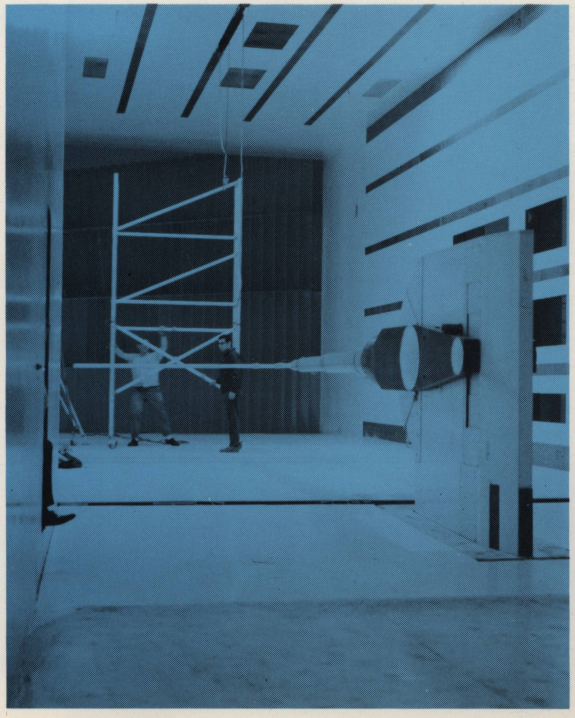
AUXILIARY POWER SUPPLY

Systems requiring auxiliary power are the Moving Belt Ground Plane, Dynamic Rotor Test Stand, the Rotor Test Stand, and powered rotor or propeller models.

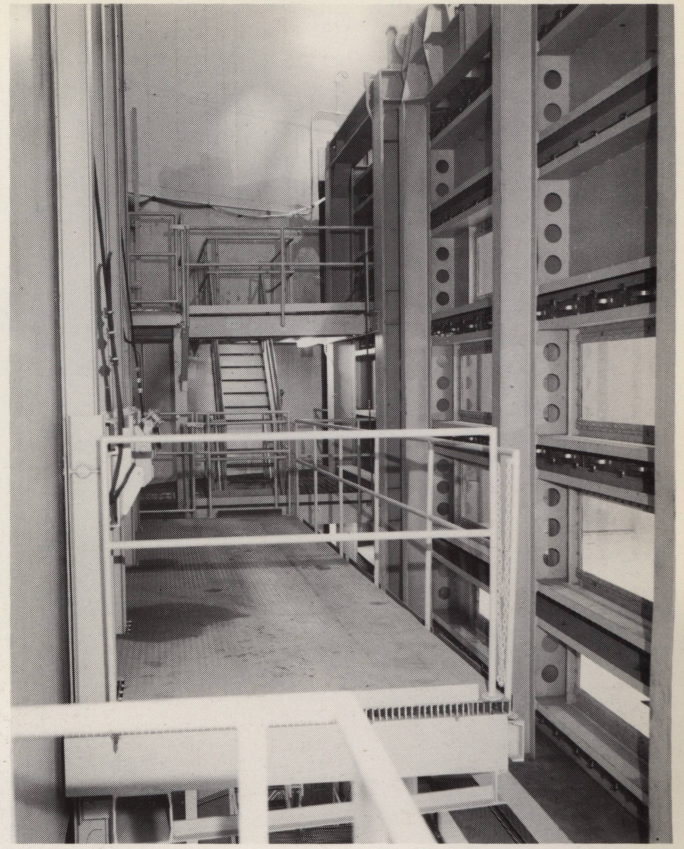
The power supplies available in the tunnel include the following units: a 57 horsepower (1 volt/Hz, 0-400 Hz); a 125 horsepower (0.5, 1.0, 2.0 volts/Hz, 0-600 Hz); a 250 horsepower (0.5, 1.0 V/Hz, 0-600 Hz) and a 400 horsepower (0.5, 1.0, and 2.0 volts/Hz, 800 V/400 Hz). These power supplies are located in the motor control center and will be controlled from the main tunnel control console.



Auxiliary air supply system



Sting support system



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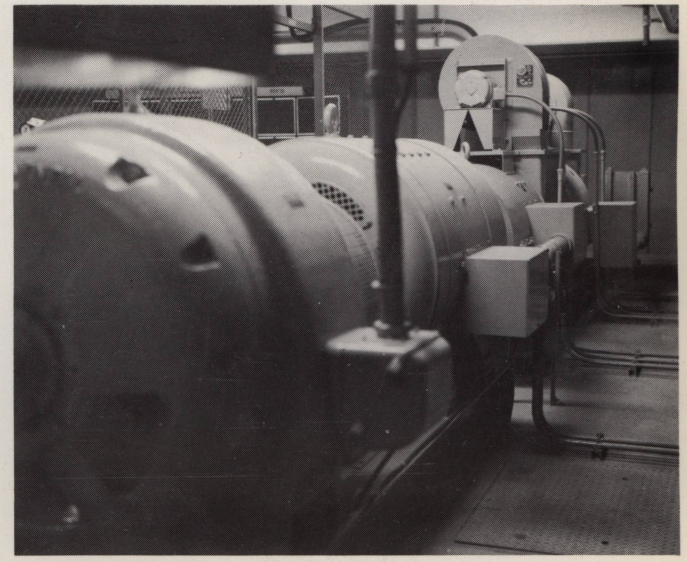
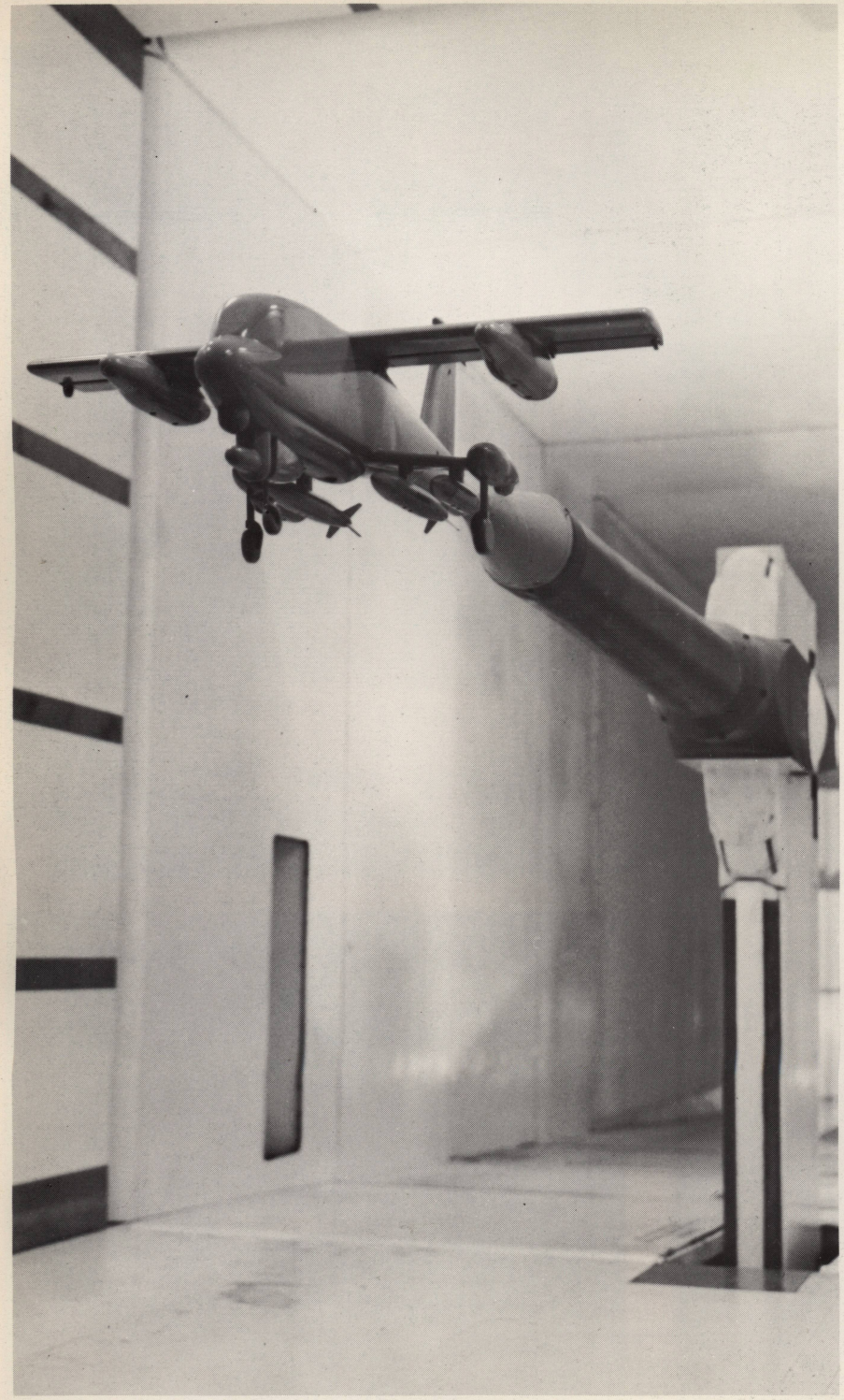
Movable observation platform



Auxiliary power supply



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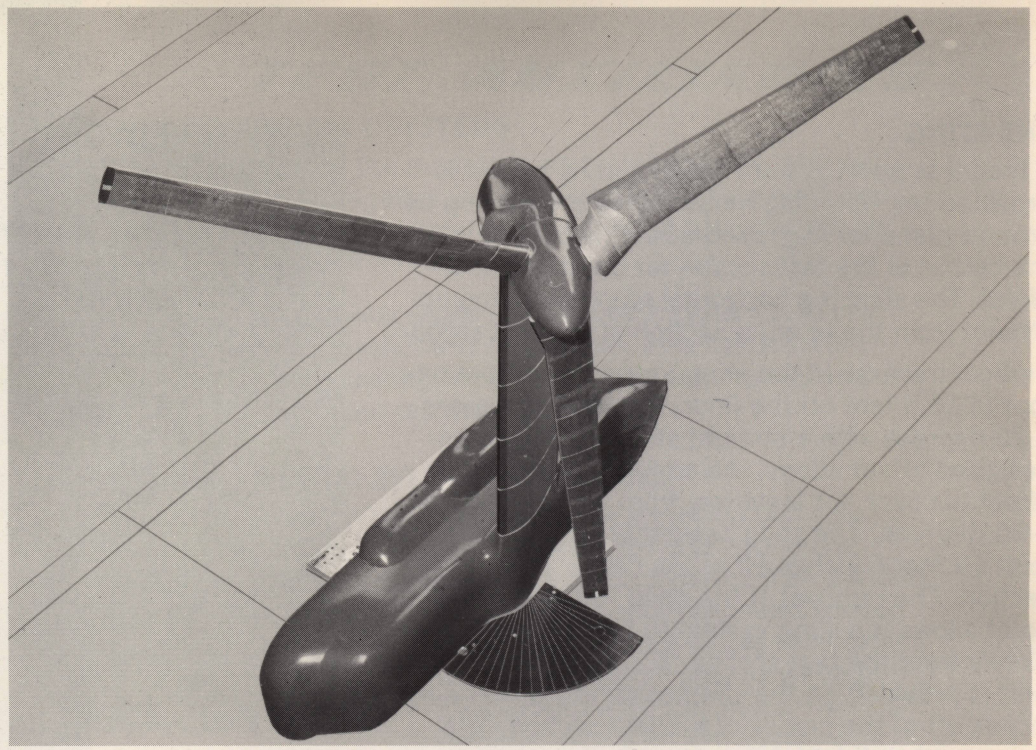
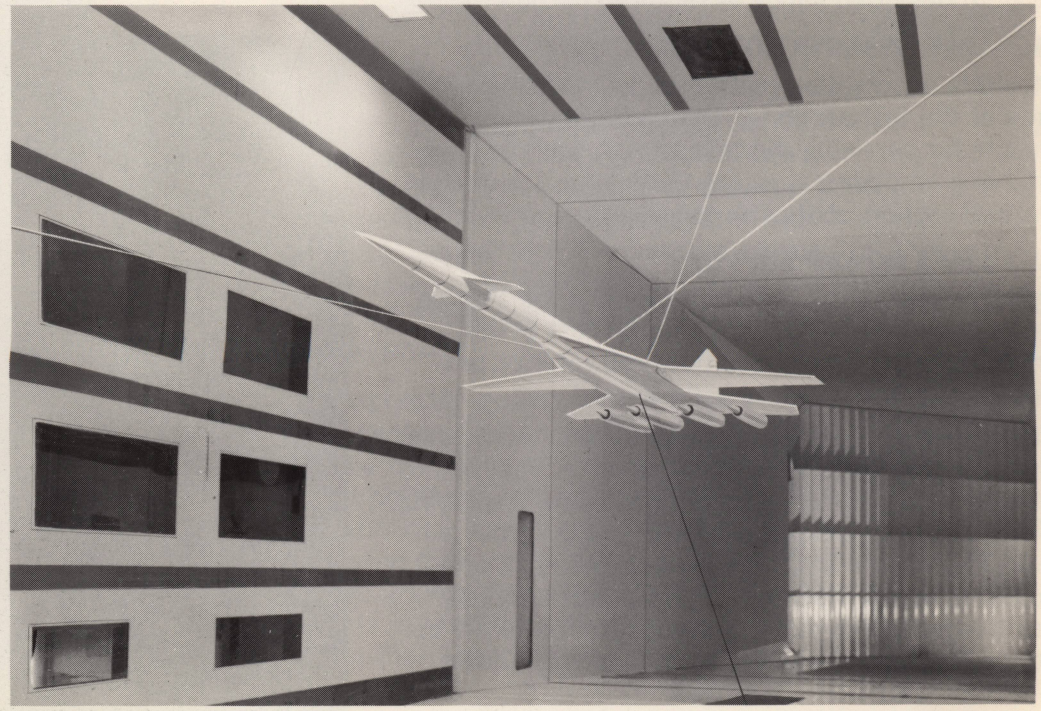
Sting-mounted model



SIMULATED 130890

Half-model installation



SIMULATED 130891

Flutter model installation

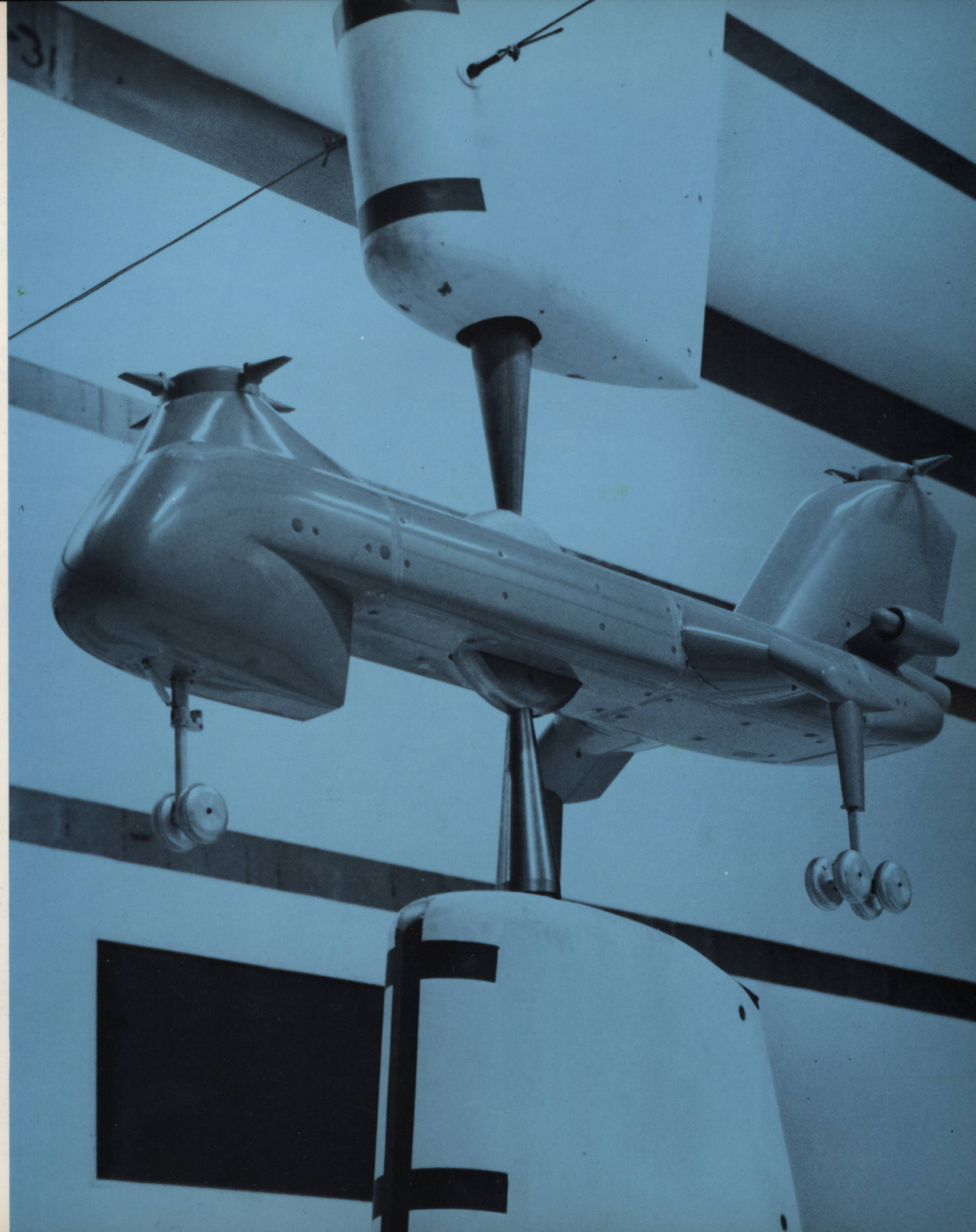
TEST INSTALLATIONS

There are four typical model installations: 1) sting-mount, 2) half-model mount, 3) flutter model mount, and 4) pedestal mount.

Sting-mounted models used to obtain force data will be mounted on internal strain gage balances. For pressure model tests, Scanivalves which sample pressures from many points and convert the pressure signals to electrical signals will be used. Auxiliary services available for the sting-mounted models include cooling water supply, model motor power supply, lubrication oil supply, auxiliary air supply, and hydraulic power supply. The pedestal-mounted models may use either internal balances or the external balance for force tests. The pressure data is handled the same way as for sting mounts. The same auxiliary services are available.

Half-model force data require the external balance. The pressure data and auxiliary provisions are the same as above.

The flutter model installation, which places limited restraints on the model, enables the model to support its own weight in the air stream and move through a limited range in vertical translation and in pitch, roll, and yaw. The model is flown with remote controls to establish flutter speeds for given aircraft configurations. Data transfers and 24-volt model motor power are provided through a trailing cable.



Pedestal-mounted model with image system installed

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Model design area

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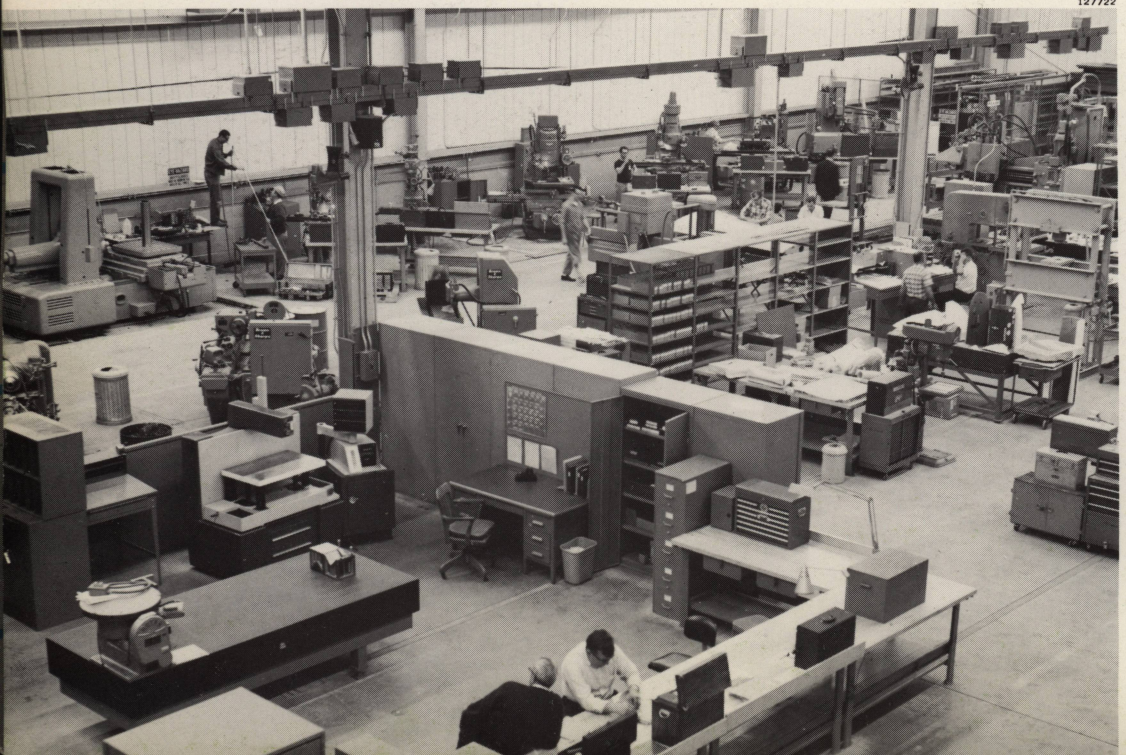

Model shop

SUPPORT BUILDING

The support building consists of a single-level model shop and a two-story engineering office and testing support area.

The model shop has the capability for working both ferrous and non-ferrous metals. Separate wood and plastic shops are included as well as an extensive instrumentation laboratory and a paint spray area.

The first floor includes a model assembly, calibration, and checkout area contiguous to the plenum. The second floor is on test section level. An instrumentation and data control room is directly adjacent to the test section for personnel supporting the test in progress. A dual conference room/theater for viewing test films and studying test results is also available on the second floor. Also, an office is provided for customer representatives.

Testing and analysis area

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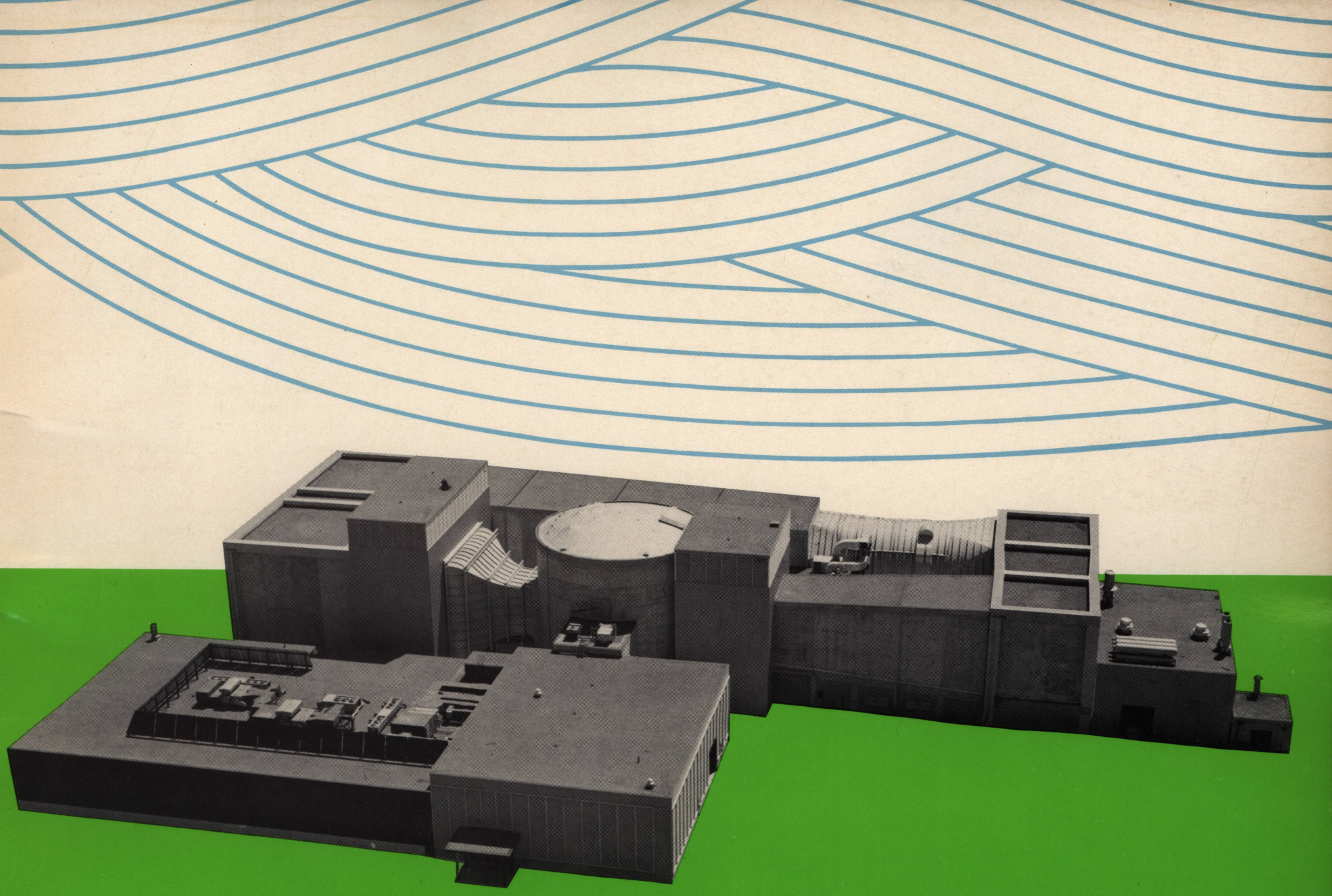

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